# Constraints on B and Higgs Physics in MSSM

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## Outline

1. The effective resummed MSSM Lagrangian.
2. Contributions to $\Delta M_s$ and $B_s \to \mu^+\mu^-$ in MSSM.
3. $\mathcal{B}R(B_s \to \mu^+\mu^-)$ and $\Delta M_s$ in the MSSM.
4. $b \to s\gamma$ and $B_s \to \mu^+\mu^-$ constraints on Higgs searches.

Based on:

M. Carena, A. Menon, R. Noriega-Papaqui, A. Szynkman and

C. Wagner,[arXiv:hep-ph/0603107];

# The Effective Resummed MSSM Lagrangian

- Resumming the SUSY loop corrections to the quark masses leads to an effective mass Lagrangian for the down quarks.

$$-\mathcal{L}_m = \bar{d}_R \mathbf{m_d}[1 + \tan\beta \left(\epsilon_\mathbf{0} + \mathbf{V_0^\dagger} \epsilon_\mathbf{Y} |\mathbf{Y_u}|^\mathbf{2} \mathbf{V_0}\right)] d_L + h.c.$$

where $V_0$ is the tree-level CKM matrix and for uniform squark masses

$$|\epsilon_0| \approx \frac{2\alpha_s}{3\pi} |M_3||\mu| C_0(m^2_{\tilde{b}_1}, m^2_{\tilde{b}_2}, |M_3|^2)$$

$$|\epsilon_Y| \approx \frac{1}{16\pi^2} |A_t||\mu| C_0(m^2_{\tilde{t}_1}, m^2_{\tilde{t}_2}, |\mu|^2)$$

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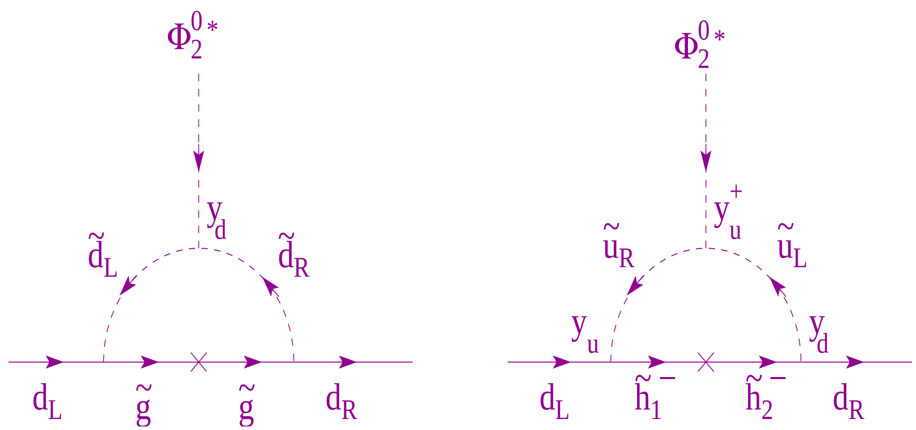


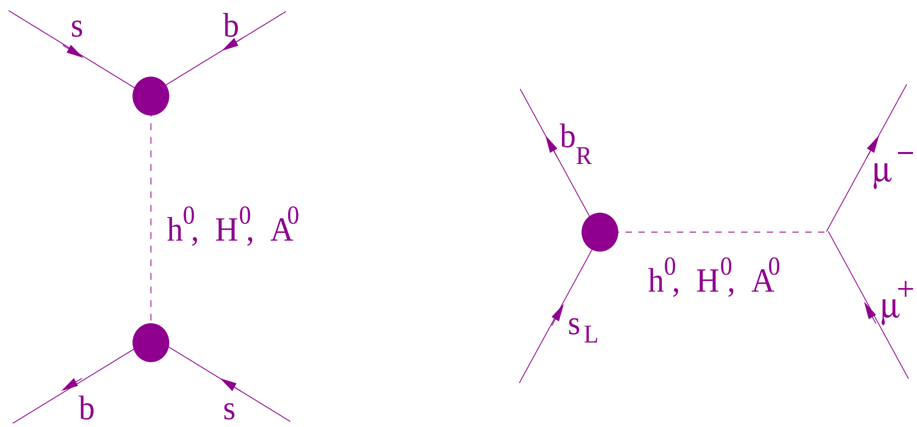

- The quark mass matrices need to be rediagonalized. Thereby inducing Flavor Changing Neutral Currents (FCNC) $\propto V^{3J*} V^{3I}$.

# Constraints on B Physics in the MSSM

# Contributions to $\Delta M_s$ and $B_s \to \mu^+\mu^-$ in MSSM

- At large $\tan\beta$ the double penguin contribution to $\Delta M_s$ is dominant and $\propto |\epsilon_Y|^2 \tan^4\beta / M_A^2$, which interferes destructively with the SM.
- Similarly for large $\tan\beta$ the dominant contribution to $B_s \to \mu^+\mu^- \propto |\epsilon_Y|^2 \tan^6\beta / M_A^4$
- Therefore values of $B_s \to \mu^+\mu^-$ and $\Delta M_s$ at large $\tan\beta$ are correlated. So for uniform squark masses the only SUSY dependence in their ratio is

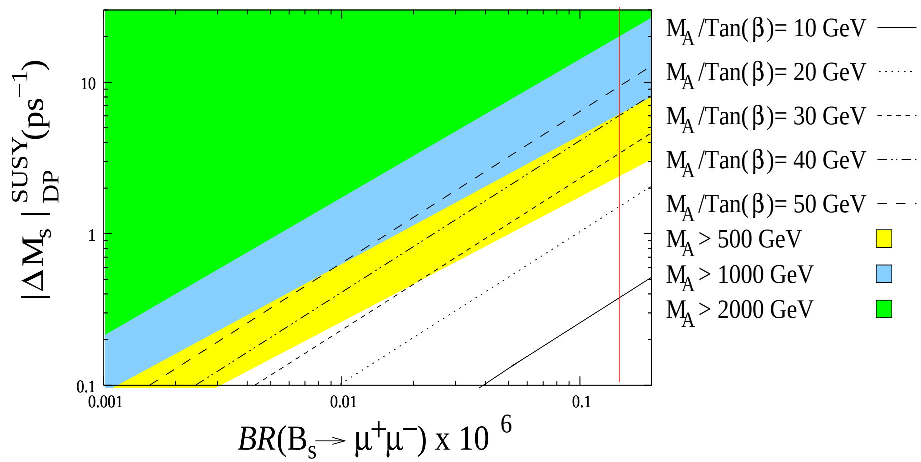
$$\frac{\Delta M_s}{\mathcal{BR}(B_s \to \mu^+\mu^-)} \propto \frac{M_A^2}{\tan^2\beta}$$




- For moderate or low $\tan\beta$ the large contributions to $\Delta M_s$ are possible for light stops, charginos or gluinos.

# The $B_s \to \mu^+\mu^-$ bound and its constraint on double penguin contributions to $\Delta M_s$

- The experimental bound on $\mathcal{BR}(B_s \to \mu^+\mu^-) \leq 1.5 \times 10^{-7}$.
  R. Bernhard *et al.* [CDF Collaboration], [arXiv:hep-ex/0508058];



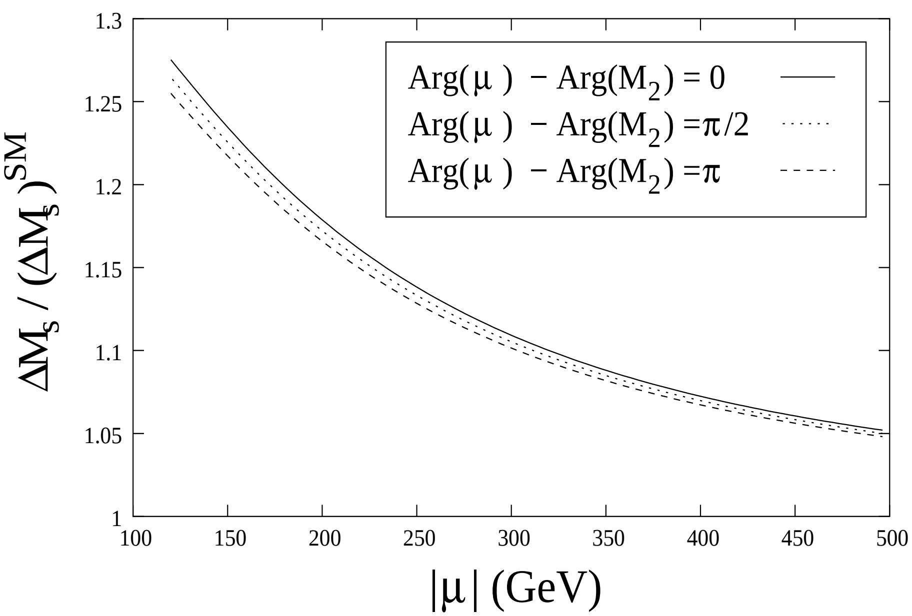

- The D0 experimental bound on $\Delta M_s = (19 \pm 2)\mathrm{ps}^{-1}$.
  V. Abazov *et al.* [D0 Collaboration], [arXiv:hep-ex/0603029];

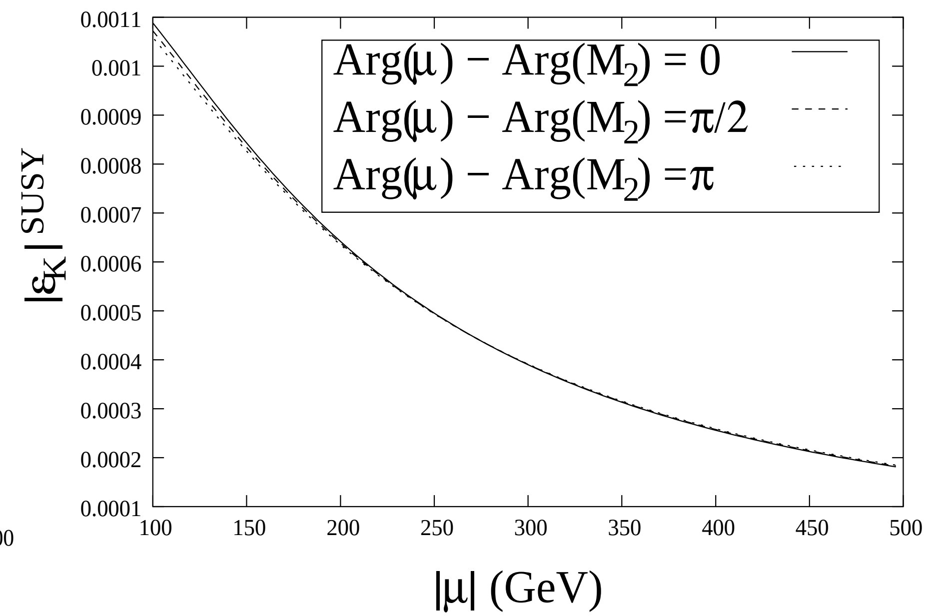
- The SM allowed range is $15.6\mathrm{ps}^{-1} \geq \Delta M_s \leq 29.7\mathrm{ps}^{-1}$ with a central value $18\mathrm{ps}^{-1}$.
  J. Charles *et al.* [CKMfitter Group], Eur. Phys. J. C **41**, 1 (2005) [arXiv:hep-ph/0406184];

- Large double penguin contributions to $\Delta M_s$ that do not violate the $B_s \to \mu^+\mu^-$ bound require large $\epsilon_Y$ and $\epsilon_0 \Rightarrow M_3 \sim 2M_{\tilde{q}} \sim \mu$. Also these contributions subtract from the SM.

# $\Delta M_s$ in the light stop scenario

- Light stops and charginos can give large contributions to $\Delta M_s$ even for low values of $\tan\beta$.
- However this kind of SUSY particle spectrum can induce large contributions to $\epsilon_K$ for SM CP phase $\sim \pi/3$ .
- The experimentally measured value of $\epsilon_K = (2.282 \pm 0.014) \times 10^{-3}$



# Constraints on Higgs Searches at the Tevatron

# $b \to s\gamma$ and $B_s \to \mu^+\mu^-$ constraints on Higgs searches at the Tevatron

- The experimental bound on $\mathcal{BR}(b \to s\gamma) = 3.38^{+0.3}_{-2.8} \times 10^{-4}$.
- The theoretical error on the SM value: $\mathcal{BR}(b \to s\gamma)^{Exp} - \mathcal{BR}(b \to s\gamma)^{SM} \leq 1 \times 10^{-4}$.

M. Neubert, Eur. Phys. J. C **40**, 165 (2005), [arXiv:hep-ph/0408179]

- The Charged Higgs is approximately $\tan\beta$ independent and adds to the SM value of $b \to s\gamma$.
- While the Chargino-Stop contribution grows with $\tan\beta$ and for negative $\mu A_t$ subtracts from the SM value. Therefore by varying $\mu A_t$ and $\tan\beta$ the SUSY contributions can approximately cancel each other.
- The Tevatron reach at large $\tan\beta$ can be calculated approximately using the relation

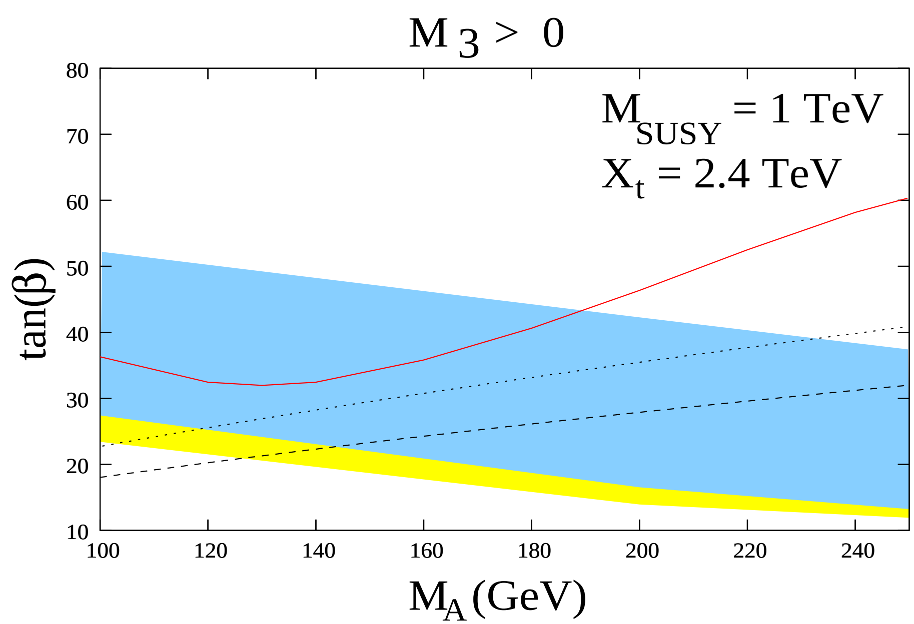
$$\sigma(gg, b\bar{b} \to A) \times \mathcal{BR}(A \to \tau^+\tau^-) \sim \sigma(gg, b\bar{b} \to A)_{SM} \frac{\tan^2\beta}{(1 + \epsilon_0 \tan\beta)^2 + 9}$$

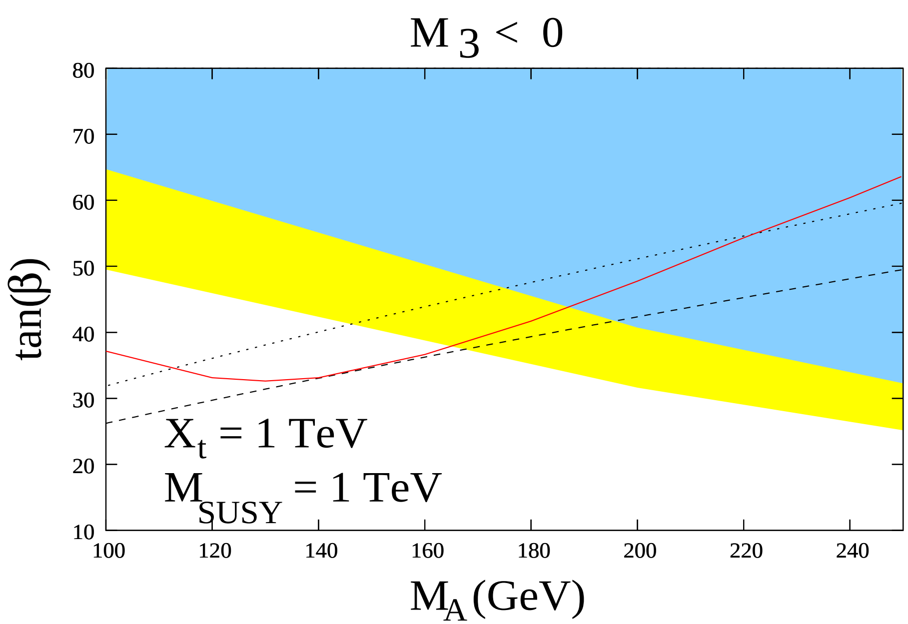
M. Carena *et al.*, [arXiv:hep-ph/0511023]

# The Maximal Mixing Scenario

- The Maximal Mixing scenario is one in which the mass of the lightest CP even Higgs is maximized, due maximal mixing in the stop sector.
- The SUSY parameters in this scenario are

$$M_{SUSY} = 1\text{TeV}, \;\; |M_3| = 0.8 M_{SUSY}, \;\; M_A \leq 1000\text{GeV},$$
$$\mu \ll 1\text{TeV}, \;\; X_t = A_t - \frac{\mu}{\tan\beta} = \sqrt{6} M_{SUSY} = 2.4\text{TeV}$$



# The Minimal Mixing scenario

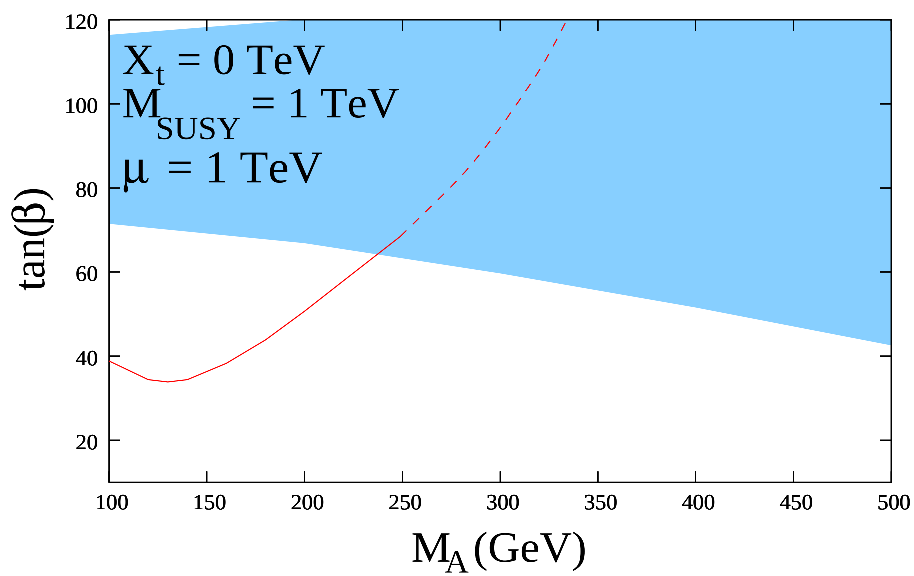
- The Minimal Mixing scenario has not mixing in the stop sector. Therefore the lightest CP even higgs has a mass close to the LEP bound. The SUSY parameters are the same as Maximal Mixing except $X_t = 0$ and $\mu \geq 1\text{TeV}$.

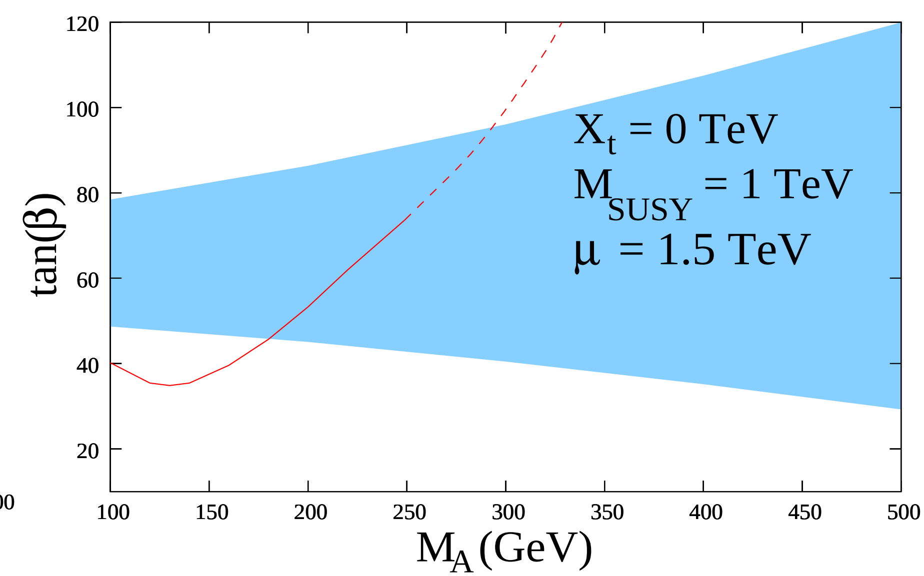
- $\mathcal{BR}(B_s \to \mu^+\mu^-) \propto A_t$, and so puts no constraint on the $M_A - \tan\beta$ plane.

- The Charged Higgs amplitude for $b \to s\gamma$ is also small for large $\mu, M_3$ and $\tan\beta$ as:

$$A_{H+} \propto 1 - \frac{2\alpha_s}{3\pi}\mu M_3 \tan\beta \left(\cos^2\theta_{\tilde{t}} C_0(m^2_{\tilde{s}_L}, m^2_{\tilde{t}_1}, M_3^2) + \sin^2\theta_{\tilde{t}} C_0(m^2_{\tilde{s}_L}, m^2_{\tilde{t}_2}, M_3^2)\right).$$

- For these SUSY values the Chargino-Stop contribution is also small.



# Conclusions

- Within the MSSM the measurement of $\Delta M_s$ at D0 and the CDF bound on $B_s \to \mu^+\mu^-$ are self consistent.

- Searches for Non Standard Model Higgses at the Tevatron are highly constrained for the Maximal Mixing scenario.

- But the Minimal Mixing scenario looks much more promising.

- Observation of a Non Standard Model Higgs at the Tevatron would imply either moderate values of $X_t$ for small $\mu$ or vice versa.